Evaluation of SPLAT with Spinosad and Methyl Eugenol or Cue-Lure for "Attract-and-Kill" of Oriental and Melon Fruit Flies (Diptera: Tephritidae) in Hawaii

ROGER I. VARGAS,[1] JOHN D. STARK,[2] MARK HERTLEIN,[3] AGENOR MAFRA NETO,[4] REGINALD COLER,[4] AND JAIME C. PIÑERO[5]

J. Econ. Entomol. 101(3): 759–768 (2008)

ABSTRACT Specialized Pheromone and Lure Application Technology (SPLAT) methyl eugenol (ME) and cue-lure (C-L) "attract-and-kill" sprayable formulations containing spinosad were compared with other formulations under Hawaiian weather conditions against oriental fruit fly, *Bactrocera dorsalis* (Hendel), and melon fly, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae), respectively. Field tests were conducted with three different dispensers (Min-U-Gel, Acti-Gel, and SPLAT) and two different insecticides (naled and spinosad). SPLAT ME with spinosad was equal in performance to the standard Min-U-Gel ME with naled formulation up to 12 wk. SPLAT C-L with spinosad was equal in performance to the standard Min-U-Gel C-L with naled formulation during weeks 7 to12, but not during weeks 1–6. In subsequent comparative trials, SPLAT ME + spinosad compared favorably with the current standard of Min-U-Gel ME + naled for up to 6 wk, and it was superior from weeks 7 to 12 in two separate tests conducted in a papaya (*Carica papaya* L.) orchard and a guava (*Psidium guajava* L.) orchard, respectively. In outdoor paired weathering tests (fresh versus weathered), C-L dispensers (SPLAT + spinosad, SPLAT + naled, and Min-U-Gel + naled) were effective up to 70 d. Weathered ME dispensers with SPLAT + spinosad compared favorably with SPLAT + naled and Min-U-Gel + naled, and they were equal to fresh dispensers for 21–28 d, depending on location. Our current studies indicate that SPLAT ME and SPLAT C-L sprayable attract-and-kill dispensers containing spinosad are a promising substitute for current liquid organophosphate insecticide formulations used for areawide suppression of *B. dorsalis* and *B. cucurbitae* in Hawaii.

KEY WORDS SPLAT, male annihilation, *Bactrocera dorsalis*, *Bactrocera cucurbitae*, fruit fly suppression

Oriental fruit fly, *Bactrocera dorsalis* (Hendel), and melon fly, *Bactrocera cucurbitae* (Coquillett) (Diptera: Tephritidae), are major fruit fly pest species in Hawaii with 173 and 125 host plant species recorded, respectively (Weems 1964, Metcalf and Metcalf 1992). *Bactrocera* is a tephritid fly genus of at least 440 species distributed primarily in tropical Asia, the South Pacific, and Australia (White and Elson-Harris 1992). At least 90% of the male Dacinae species (made up of the two major genera *Bactrocera* Macquart and *Dacus* F.) are strongly attracted to either methyl eugenol (ME; 4-allyl-1, 2-dimethoxybenzene-carboxylate) or cue-lure (C-L; 4-(*p*-acetoxyphenyl)-2-butanone) (Hardy 1979). Owing to their powerful male-specific attractiveness (Metcalf and Metcalf 1992), both ME and C-L lures have been used successfully in male annihilation systems against *B. dorsalis* and *B. cucurbitae,* respectively (Chambers et al. 1974).

As part of a 10-yr program to promote areawide integrated pest management (IPM) methods in Hawaii for fruit fly suppression and to reduce the use of organophosphate insecticides (Vargas et al. 2008, Mau et al. 2007), GF-120 Fruit Fly Bait has replaced malathion protein baits. However, "attract-and-kill" male lure devices without organophosphate insecticides are still being researched and developed for registration in the United States. Of particular interest would be a sprayable formulation with a reduced risk insecticide. In Hawaii, Vargas et al. (2003) demonstrated spinosad bucket traps with ME and C-L lures to be an organophosphate alternative. However, traps are expensive and often inconvenient to use. In Nauru and French Polynesia Allwood et al. (2002) tested fipronil stations with ME and C-L (and fipronil) against *B. dorsalis*, *B.*

This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation by the USDA for its use.

[1] Corresponding author: U.S. Pacific Basin Agricultural Research Center, USDA–ARS, P.O. Box 4459, Hilo, HI 96720 (e-mail: roger.vargas@ars.usda.gov).

[2] Washington State University, Puyallup Research and Extension Center, Puyallup, WA 98371.

[3] Dow AgroSciences, 9330 Zionsville Rd., Indianapolis, IN 46268.

[4] ISCA Technologies, 2060 Chicago Ave., Suite C2, Riverside, CA 92517.

[5] College of Tropical Agricultural and Human Resources, University of Hawaii at Manoa, 3050 Maile Way Honolulu, HI 96822.

cucurbitae, *Bactrocera xanthodes* (Broun), and *Bactrocera frauenfeldi* (Shiner) as a substitute for malathion. Barry et al. (2004) tested fipronil in an attract-and-kill station system for control of *Rhagoletis mendax* Curran, the blueberry maggot.

Min-U-Gel formulations with ME were developed for spot applications in male annihilation programs in California for eradication of *B. dorsalis* (Chambers et al. 1974, Cunningham and Suda 1985). Min-U-Gel is a fine grade of attapulgite clay (anhydrous magnesium aluminum silicate) mixed with naled or malathion and ME to form a gel male annihilation formulation. Acti-Gel is a refined grade of Min-U-Gel. However, Min-U-Gel and similar thickened formulations are not long-lived when weathered in areas with warm temperatures and high rainfall (Cunningham et al. 1975a,b; Cunningham and Suda 1985, Vargas et al. 2000).

Specialized Pheromone and Lure Application Technology (SPLAT) is a proprietary base matrix formulation of biologically inert materials used to control the release of semiochemicals and/or odors with or without pesticides. Extensive research on SPLAT using a variety of lures suggested that this matrix emits semiochemicals at effective pest suppression levels for a time interval ranging from 2 to 16 wk. Having a wide range of viscosities and application methods (e.g., applicator sprays, aerial applicator sprays, caulking gun type tubes), SPLAT increases productivity by mechanizing the application of pheromone dispensing points (Stelinski et al. 2007). The amorphous and flowable quality of this highly adaptable product allows for an easy transition from small-scale manual applications to large-scale manual or mechanical applications.

Spinosad, a mixture of spinosyns A and D, soil fermentation products of the soil bacterium *Saccharopolyspora spinosa* Mertz and Yao, is active at low application rates against many economically important pest insects, has low mammalian toxicity, and reduced environmental impact on natural enemies (DowElanco 1994, Stark and Vargas 2003, Stark et al. 2004). Spinosad works by contact and by ingestion. A hydrolyzed protein bait with spinosad that attracts, induces feeding, and kills fruit flies has been produced as GF-120 Fruit Fly Bait (Dow AgroSciences, Indianapolis, IN) (Prokopy et al. 2003, Barry et al. 2006). The objective of the current study was to test the performance of ME and C-L sprayable formulations with spinosad under Hawaiian climatic conditions to attract and kill male *B. dorsalis* and *B. cucurbitae* flies. We compared a novel SPLAT formulation with spinosad with similar available formulations containing the organophosphate insecticide naled.

Materials and Methods

Experiment 1. Comparison of SPLAT, Min-U-Gel, and Acti-Gel ME and C-L Formulations. For each of the two male lures (ME and C-L), six different formulations, determined by the combination of three different carriers (SPLAT, Min-U-Gel, and Acti-Gel) and two different insecticides (spinosad and naled), were evaluated: 1) SPLAT (ISCA Technologies, Riverside, CA) + spinosad (Success, Dow AgroSciences, Indianapolis, IN), mixed as a proprietary formulation by ISCA Technologies; 2) SPLAT + naled (Dibrom Concentrate, Valent USA Corp., Walnut Creek, CA), mixed on site to a similar consistency as the SPLAT + spinosad; 3) Min-U-Gel (Min-U-Gel 400, Floridin Co., Quincy, FL) + naled, a formulation developed by Cunningham and Suda (1985) for spot treatments in California; 4) Min-U-Gel + spinosad; 5) Acti-Gel (Acti-Gel 208, Floridin Co., Quincy, FL) + spinosad; and 6) Acti-Gel + naled. Approximately, 4.5 ml of each material was loaded onto 4.0-cm-diameter- by 0.5-cm-thick wooden disks. Each of six disks with ME or C-L treatments was hung inside a fruit fly bucket trap fabricated from plastic containers (Highland Plastic no. 36, 1-liter containers, 3.5-cm radius, 15 cm in height, with four 3-cm-diameter holes) illustrated in Vargas et al. (2003) and evaluated according to the methods described in Vargas et al. (2005). ME and C-L liquid lures were purchased from Farma Tech International (Seattle, WA).

Trials of different ME formulations (for *B. dorsalis*) were conducted from 15 Feb. 2006 to 10 May 2006 in a papaya, *Carica papaya* L., field at the University of Hawaii Experiment Station at Wailua, Kauai Island, HI. Mean $\pm$ SEM monthly temperature and rainfall were $21.78 \pm 1.19°C$ and 29.30 ± 24.01 cm, respectively, during the evaluation period. Fruit fly bucket traps (20 m apart) were placed on fiberglass stakes 1 m above the ground and arranged in four replicate rows of six treatments throughout the orchard in a randomized complete block design (four blocks). To compensate for position effects, traps were rotated one position each week until all six positions in a row had been occupied by each trap. Therefore, comparisons of pooled trap captures by treatment were made at 6 and 12 wk. Fruit flies from traps containing treatments were emptied at weekly intervals into plastic bags and transported to the laboratory where counts were done.

Cue-lure dispensers (for *B. cucurbitae*) were evaluated from 16 February 2006 to 11 May 2006 at Polihale, Kauai Island, HI (mean $\pm$ SEM monthly temperature and rainfall, $23.01 \pm 0.71°C$, 4.09 ± 1.63 cm), where bitter melon, *Momordica charantia* L., is a common weed (Vargas et al. 2003). Bucket traps (described above) were placed 20 m apart on fiberglass stakes 1 m above the ground in four patches of bitter melon under kiawe [*Prosopis pallida* (Humb. and Bonpl. ex Willd.) Kunth] and koa haole [*Leucaena leucocephala* (Lam.) de Wit] trees throughout the area in a randomized complete block design (four blocks). Trap rotation and counts of *B. cucurbitae* were as described above.

For each fly species, data for daily captures (mean number of flies per trap per day) were subjected to analysis of variance (ANOVA) and means separated with a Fisher least significant difference (LSD) test at the $P = 0.05$ level (SAS Institute 1999).

Experiment 2. Comparison of Weathered Min-U-Gel Naled, SPLAT Naled, and SPLAT Spinosad ME and C-L. Three different formulations were compared for each of the two male lures (ME and C-L): 1)

SPLAT + spinosad; 2) SPLAT + naled; and 3) Min-U-Gel + naled. For each of these three ME/C-L formulations, 48 disks (circular wooden disks 4.0 cm in diameter by 0.5 cm in thickness, with a 4-mm-diameter hole for a 125-mm long wire) were hung using wires from six horizontal ropes (three each for ME and C-L), stretched between branches of six lychee (*Litchi chinensis* Sonn.) trees at the University of Hawaii Experiment Station at Wailua, Kauai Island, HI, according to the methods of Vargas et al. (2003, 2005). All disks were exposed to daily temperature fluctuation, wind, and rain, but they were protected from direct sunlight by the tree foliage from 1 August 2006 to 10 October 2006. Mean ± SEM monthly temperature and rainfall for the weathering site were 25.13 ± 1.23°C and 15.54 ± 6.07 cm. Each week, four disks were removed from each line and taken to a field site where they were evaluated in traps.

Weathered ME dispensers (for *B. dorsalis*) were evaluated from 8 August 2006 to 19 October 2006 at Kilauea in a guava (*Psidium guajava* L.) orchard, as well as at Wailua in a grapefruit (*Citrus paradisi* Macfad.) orchard. Traps baited with the three different treatments were placed 20 m apart within a row of trees (1.5 m above the ground) in four different locations (four replicates, $n = 12$ traps) of the orchard in a randomized complete block design. To minimize the effect of trap location, traps were rotated one tree position each week until all positions in a row had been occupied by each trap. Mean ± SEM monthly temperature and rainfall were 24.54 ± 0.32°C and 16.99 ± 8.69 cm for Kilauea and 25.13 ± 1.23°C and 15.54 ± 6.07 cm for Wailua, respectively.

Cue-lure dispensers (for *B. cucurbitae*) were evaluated from 2 August to 19 October 2006 at Polihale, Kauai Island, HI (mean ± SEM monthly temperature and rainfall, 25.83 ± 0.34°C and 3.76 ± 2.74 cm, respectively). Traps were placed 20 m apart on fiberglass stakes 1 m above the ground in four patches of wild bitter melon.

As in the first experiment, traps were emptied weekly into plastic bags and transported to the laboratory where counts were done. Data for daily captures (mean number of flies per trap per day) were analyzed separately for each fly species and subjected to ANOVA. Means were separated with a Fisher LSD test at the $P = 0.05$ level (SAS Institute 1999) at 3-wk intervals.

Experiment 3. Comparison of Weathered against Fresh Min-U-Gel Naled, SPLAT Naled and SPLAT Spinosad ME and C-L. Disks were prepared and aged as described in experiment 2. At 1-wk intervals, four ME or four C-L stations were removed at random from the "exposure line," placed inside plastic bags, and transported to the field trial site. To provide a reference for efficacy of weathered stations, a fresh ME or C-L treatment was taken from a sealed bucket containing fresh material. Disks with different treatments were placed inside traps and fruit fly captures recorded as described above.

For ME dispensers, four pairs of traps baited with fresh and weathered (7, 14, 21, 28, 35, 42, 49, and 56 d) disks were hung for 7 d in shaded locations in the lower branches of trees both in a guava orchard at Kilauea, and in a grapefruit orchard at Wailua (Kauai Island, HI). Traps were arranged in two rows and separated by 30–40 m on all sides within the orchards. Trap capture data were collected in Kilauea from 25 October 2006 to 24 January 2007 and in Wailua from 7 November to 19 December 2006. Mean ± SEM monthly temperature and rainfall were 22.50 ± 0.78°C and 17.63 ± 11.50 cm for Kilauea and 23.87 ± 1.38°C and 12.14 ± 9.42 cm, for Wailua, respectively.

For C-L dispensers, four pairs of traps baited with fresh and weathered dispensers (7, 14, 21, 28. 35, 42, 49, 56, 63, 70, and 77 d) were placed on fiberglass stakes 1 m above the ground and spaced 30 m apart near patches of wild bitter melon. Evaluations took place from 26 October 2006 to 18 January 2007 at Polihale, Kauai Island, HI (mean ± SEM monthly temperature and rainfall, 23.06 ± 1.01°C and 8.41 ± 1.14 cm, respectively).

All *B. dorsalis* and *B. cucurbitae* flies captured were removed from traps 1 wk later and counted in the laboratory. By comparing mean number of flies captured inside traps baited with either weathered or fresh stations on successive weeks, the relative attract-and-kill efficacy of the ME or C-L stations was determined. ME and C-L trap data for *B. dorsalis* and *B. cucurbitae* captures (mean number flies per trap per wk) were subjected to analysis of variance (ANOVA) (PROC GLM), and means separated with a Fisher LSD test at the $P = 0.05$ level (SAS Institute 1999).

Results

Comparison of SPLAT, Acti-Gel, and Min-U-Gel ME and C-L Formulations. In the ME trials (Fig. 1A), there was a significant effect of treatment on captures of *B. dorsalis* both during the first and second evaluation periods. For the first 6 wk, the performance of SPLAT and Min-U-Gel was similar regardless of the type of toxicant used. The Acti-Gel ME + spinosad treatment was significantly less effective than any of other five ME formulations tested. SPLAT ME + naled was the best-performing treatment throughout the 12-wk field trial. SPLAT ME + spinosad compared favorably with the standard Min-U-Gel ME + naled for up to 12 wk.

In the C-L trials (Fig. 1B), captures of *B. cucurbitae* differed significantly with treatment during the first as well as during the second evaluation periods. For the first 6 wk, all C-L formulations that used naled as a toxicant performed significantly better than those that used spinosad. Acti-Gel + naled and SPLAT + naled were the two best-performing treatments throughout the 12-wk field trial. Overall, all naled C-L formulations outperformed spinosad C-L formulations.

Comparison of Weathered Min-U-Gel Naled, SPLAT Naled, and SPLAT Spinosad ME and C-L. In trials with SPLAT containing either naled or spinosad, SPLAT ME + spinosad was equal to the current standard of Min-U-Gel ME + naled up to 6 wk and superior from weeks 7 to 12 in two separate tests conducted in

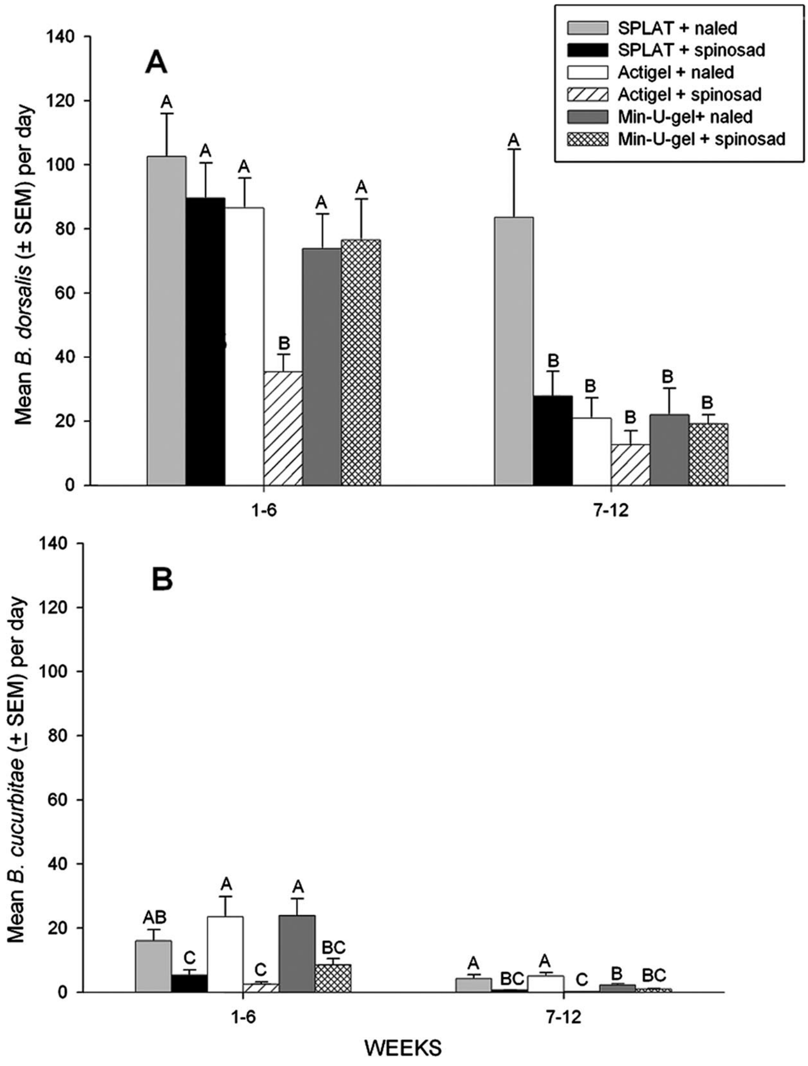

Fig. 1. Mean captures of (A) *B. dorsalis* and (B) *B. cucurbitae* per day, in traps placed either in a papaya orchard at Wailua (Kauai Island, HI) from 15 February to 3 May 2006 (for *B. dorsalis*) or in bitter melon patches at Polihale (Kauai Island, HI) from 16 February to 11 May 2006 (for *B. cucurbitae*). Bar values in the same category with the same letter are not significantly different ($\alpha = 0.05$, LSD, PROC GLM; SAS Institute 1999). For *B. dorsalis*: weeks 1–6: $F_{5,\ 138} = 4.37$: $P < 0.01$; weeks 7–12: $F_{5,\ 138} = 6.15$; $P < 0.0001$; and for *B. cucurbitae*: weeks 1–6: $F_{5,\ 114} = 5.94$; $P < 0.0001$; weeks 7–12: $F_{5,\ 138} = 8.98$; $P < 0.0001$.

the guava orchard (Table 1) and a grapefruit orchard (Table 2), respectively. SPLAT C-L + spinosad was equal to Min-U-Gel C-L with naled for up to 12 wk (Table 3).

Comparison of Weathered against Fresh Min-U-Gel Naled, SPLAT Naled, and SPLAT Spinosad ME and C-L. *Bactrocera dorsalis* captures for weathered ME dispensers were not significantly different ($P > 0.05$) than those for fresh dispensers up to 28 d during trials at Wailua (Fig. 2). Similarly, *B. dorsalis* captures for weathered ME dispensers were not significantly different ($P > 0.05$) than those for fresh dispensers up to 14 and 21 d for Min-U-Gel + naled and Splat + spinosad, respectively, at Kilauea (Fig. 3). *B. cucurbitae* captures for weathered C-L dispensers were not significantly different ($P > 0.05$) from those for fresh

Table 1. Captures (mean ± SEM flies per trap per d) of *B. dorsalis* in ME traps surveyed weekly from 8 Aug. to 24 Oct. 2006 in a guava orchard at Kilauea, Kauai Island, HI

Wk	SPLAT + naled	SPLAT + spinosad	Min-U-Gel + naled
1–3	30.51 ± 4.22a	32.29 ± 4.24a	39.73 ± 6.42a
4–6	139.97 ± 23.82a	106.26 ± 19.48a	96.65 ± 24.11a
7–9	222.23 ± 34.06a	131.29 ± 13.54b	91.87 ± 22.04b
10–12	38.35 ± 12.68b	63.92 ± 9.30a	8.78 ± 3.53c

Values in each row followed by the same letters are not significantly different at the 0.05 level LSD, PROC GLM (SAS Institute 1999) (weeks 1–3: $F_{2,\ 33} = 0.93$; $P = 0.40$; weeks 4–6: $F_{2,\ 33} = 1.02$; $P = 0.37$; weeks 7–9: $F_{2,\ 33} = 7.33$; $P = 0.002$; and weeks 10–12: $F_{2,\ 33} = 8.80$; $P = 0.0009$).

Table 2. Captures (mean ± SEM flies per trap per d) of *B. dorsalis* in ME traps surveyed weekly from 9 Aug. to 25 Oct. 2006 in a grapefruit orchard at Wailua, Kauai Island, HI

Wk	Treatment		
	SPLAT + naled	SPLAT + spinosad	Min-U-Gel + naled
1–3	11.14 ± 6.34a	7.58 ± 4.12a	9.37 ± 3.43a
4–6	96.58 ± 17.21a	112.77 ± 24.63a	55.46 ± 13.35a
7–9	147.33 ± 35.33a	153.88 ± 11.96a	34.36 ± 7.98b
10–12	41.65 ± 16.98a	70.11 ± 9.68a	4.95 ± 2.79b

Values in each row followed by the same letters are not significantly different at the 0.05 level LSD, PROC GLM (SAS Institute 1999) (weeks 1–3: $F_{2, 33} = 0.14$; $P = 0.88$; weeks 4–6: $F_{2, 33} = 2.42$; $P = 0.10$; weeks 7–9: $F_{2, 33} = 10.41$; $P = 0.0003$; and weeks 10–12: $F_{2, 33} = 8.21$; $P = 0.001$).

dispensers for up to 70 d (Fig. 4), with only two exceptions (day 28 for SPLAT + spinosad and day 21 for Min-U-Gel + naled).

Discussion

Eradication of *B. dorsalis* from Rota (Steiner et al. l965), Saipan (Steiner et al. 1970), and Okinawa (Koyama et al. 1984) and *Bactrocera papayae* Drew & Hancock from Australia (Lloyd et al. 1998), was achieved through areawide application of the male lure ME (+ toxicant). More recently, *B. dorsalis,* the ME responsive *B. xanthodes* and the C-L responsive *B. cucurbitae* were eradicated from Nauru Island using MAT and protein bait sprays (Allwood et al. 2002). In spite of being used successfully for many eradication programs throughout the Pacific, male annihilation with ME or C-L is still not legally available in Hawaii for fruit fly control. As a first step to make ME and C-L products more generally available to farmers, Manufacturer's Use Permits were obtained from the U.S. Environmental Protection Agency in 2005 and 2006 for C-L and ME, respectively, in support of the Hawaii Area-Wide Pest Management program (Vargas et al. 2007). Registration focus in Hawaii is now on male annihilation end products that can be used alone in a trap, with an insecticide inside a trap, or as a sprayable formulation with a reduced-risk insecticide. Our current studies indicate that the sprayable formulations SPLAT ME and C-L containing spinosad would be a convenient and safe end product containing a ready-to-use lure and insecticide mixture worthy of registration for general grower use in areawide IPM programs.

Male annihilation technique carriers commonly used throughout the Pacific include fiberboard blocks, cotton wicks, Min-U-Gel, and molded paper fiber (Vargas et al. 2000, 2005). Fiberboard blocks impregnated with ME and various organophosphate insecticides (e.g., naled and malathion) were used to eradicate *B. dorsalis* from Rota (Steiner et al. 1965), Saipan (Steiner et al. 1970), Okinawa (Koyama et al. 1984), and *B. papayae* from Australia (Cantrell et al. 2002). Cotton wicks saturated with ME or C-L inside bucket traps (Vargas et al. 2000) have been used for suppression of *B. dorsalis* and *B. cucurbitae* in the Hawaii Fruit Fly Area-Wide IPM program. Enclosing wicks inside bucket traps not only provided protection from the weather (lasting up to 20 wk) but also made the device visible, retrievable, and reusable with limited environmental contamination and exposure to humans and pets. More recently solid lure and insecticide formulations have been substituted for cotton wicks in traps. Amulet C-L (BASF, Melbourne, Australia) molded paper fiber stations (Vargas et al. 2005) are currently registered for control of *Bactrocera tryoni* (Froggatt) in Australia. However, placement of many traps or paper stations in the field can be very time-consuming, and it is not always ideal for eradication programs. Min-U-Gel with an insecticide was developed for sprayable application to telephone poles and tree trunks in California and Florida for eradication of *B. dorsalis* (Chambers et al. 1974, Cunningham and Suda 1985). However, Min-U-Gel and other thickened formulations when weathered in habitats with warm temperatures and high rainfall are not long-lived (Cunningham and Suda 1985; Cunningham et al. 1975a,b), often lasting <2 wk (Vargas et al. 2000). The current study represents the first report documenting that SPLAT in association with the parakairomone lures ME and C-L performs at least similarly or better than other commercial carriers such as Min-U-Gel and Acti-Gel. For example, in comparative trials, the SPLAT ME formulation outperformed the Min-U-Gel ME formulation after 7–12 wk. SPLAT has a waxy outer coating that acts as a reservoir with time-released properties that allow the lure to last longer when applied to surfaces than Min-U-Gel. SPLAT, like Min-U-Gel, can be sprayed from small sprayers, trucks, and aircraft, making the technology convenient and flexible.

The most popular organophosphate insecticides used for male annihilation include naled, malathion, and 2,2-dichorovinyl dimethyl phosphate (DDVP) (Vargas et al. 2003). These insecticides, in particular naled and DDVP, are highly toxic and pose serious concerns in terms of potential negative effects on human and environmental health. Previously, Lloyd et al. (1998) found that ME and malathion (maldison) efficacy with fiberboard blocks followed an exponential curve over 52 wk. They showed that after 8 wk of exposure to weather the efficacy of blocks was reduced by 50% in comparison with a new block and that

Table 3. Captures (mean ± SEM flies per trap per d) of *B. cucurbitae* in C-L traps surveyed weekly from 2 Aug. to 18 Oct. 2006 in bitter melon patches at Polihale, Kauai Island, HI

Wk	Treatment		
	SPLAT + naled	SPLAT + spinosad	Min-U-Gel + naled
1–3	22.68 ± 8.86	5.83 ± 1.33	21.02 ± 5.65
4–6	13.10 ± 2.07	5.12 ± 1.20	20.73 ± 7.81
7–9	7.79 ± 2.30	2.64 ± 0.74	7.51 ± 2.40
10–12	16.45 ± 10.39	4.26 ± 1.17	5.78 ± 1.61

PROC GLM (SAS Institute 1999) (weeks 1–3: $F_{2, 33} = 2.30$; $P = 0.12$; weeks 4–6: $F_{2, 33} = 2.73$; $P = 0.08$; weeks 7–9: $F_{2, 33} = 2.16$; $P = 0.13$; and weeks 10–12: $F_{2, 33} = 1.18$; $P = 0.32$).

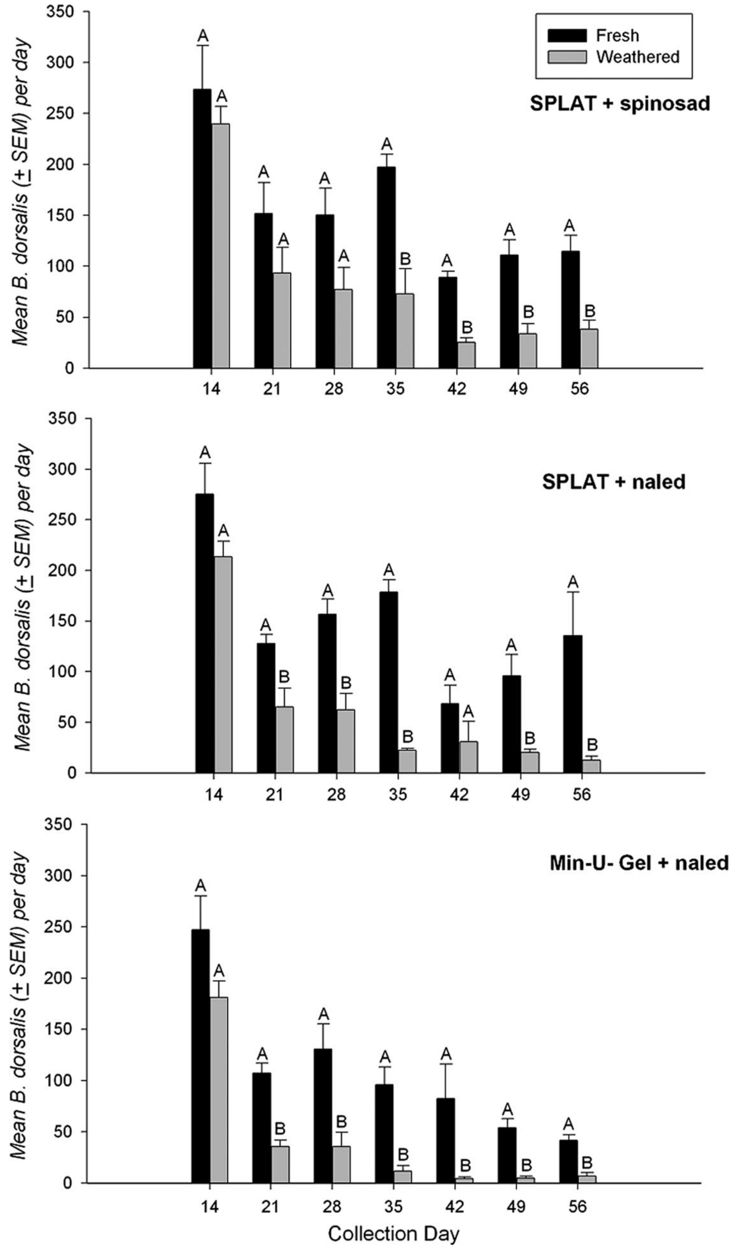

Fig. 2. Captures of *B. dorsalis* in paired ME traps with fresh and weathered treatments placed in a grapefruit orchard at Wailua, HI, from 7 November to 19 December 2006. Grouped bars with different letters are significantly different ($\alpha = 0.05$, LSD PROC GLM; SAS Institute 1999). SPLAT + spinosad: 14 d: $F_{1,6} = 0.53$; $P = 0.49$; 21 d: $F_{1,6} = 2.17$; $P = 0.19$; 28 d: $F_{1,6} = 4.60$; $P = 0.08$; 35 d: $F_{1,6} = 19.92$; $P < 0.01$; 42 d: $F_{1,6} = 69.34$; $P < 0.001$; 49 d: $F_{1,6} = 18.25$; $P < 0.01$; 56 d: $F_{1,6} = 17.57$; $P < 0.01$. SPLAT + naled: 14 d: $F_{1,6} = 3.40$; $P = 0.11$; 21 d: $F_{1,6} = 8.08$; $P = 0.03$; 28 d: $F_{1,6} = 15.13$; $P < 0.01$; 35 d: $F_{1,6} = 297.40$; $P < 0.0001$; 42 d: $F_{1,6} = 2.87$; $P = 0.14$; 49 d: $F_{1,6} = 20.61$; $P < 0.01$; 56 d: $F_{1,6} = 18.62$; $P < 0.01$. Min-U-Gel + naled: 14 d: $F_{1,6} = 3.51$; $P = 0.11$; 21 d: $F_{1,6} = 33.39$; $P = 0.001$; 28 d: $F_{1,6} = 11.55$; $P = 0.01$; 35 d: $F_{1,6} = 30.53$; $P < 0.01$; 42 d: $F_{1,6} = 14.63$; $P < 0.01$; 49 d: $F_{1,6} = 49.56$; $P < 0.001$; 56 d: $F_{1,6} = 24.64$; $P < 0.01$).

after this period the ME content was reduced by 73%. Malathion content of blocks did not change over 28 wk, with a small loss over 52 wk. Min-U-Gel with naled is currently used in California and Florida for eradication of *B. dorsalis* (Chambers et al. 1974, Cunningham and Suda 1985). Bucket traps with cotton dispensers containing ME or C-L + either naled, malathion, or DDVP proved effective against *B. dorsalis* or *B. cucurbitae* in Hawaii for >20 wk without replacement of the lure or toxicant (Vargas et al. 2003). A special local needs registration was subsequently obtained for deployment of bucket traps with

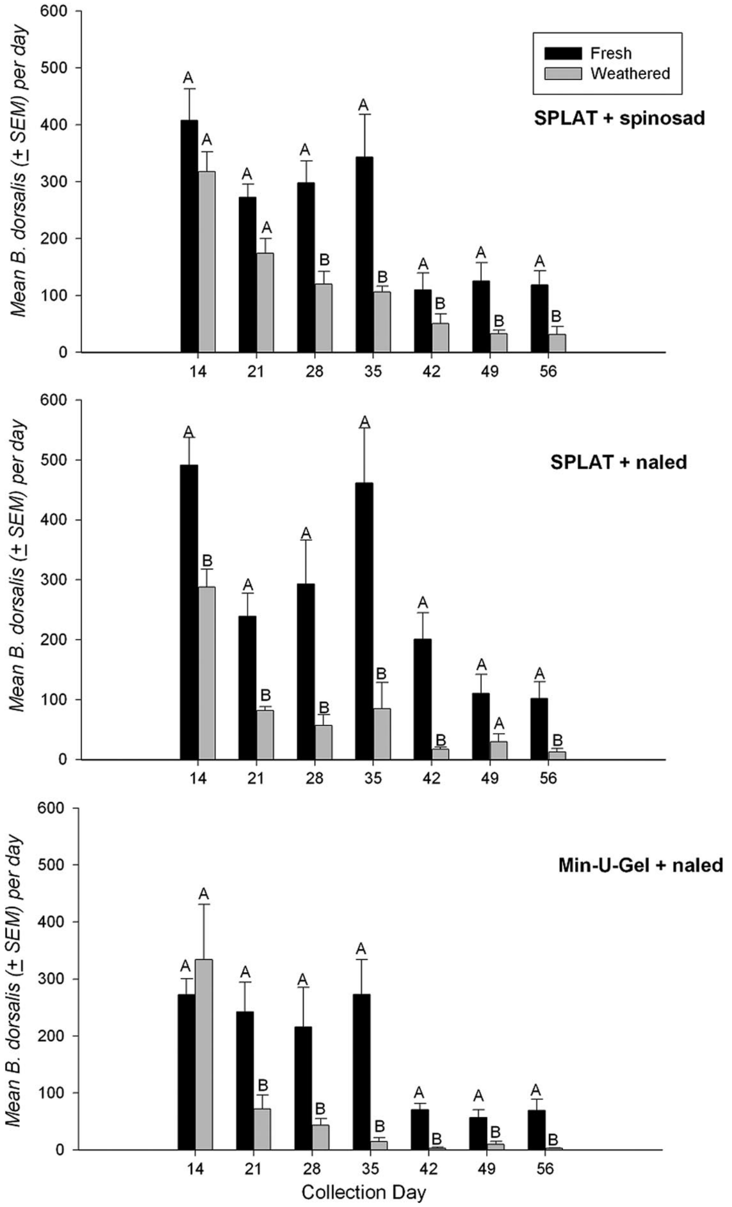

Fig. 3. Captures of *B. dorsalis* in paired ME traps with fresh and weathered treatments placed in a guava orchard at Kilauea, HI, from 11 August to 20 December 2006. Grouped bars with different letters are significantly different ($\alpha = 0.05$, LSD, PROC GLM, SAS Institute 1999). SPLAT + spinosad: 14 d: $F_{1, 6} = 1.84$; $P = 0.22$; 21 d: $F_{1, 6} = 8.07$; $P = 0.03$; 28 d: $F_{1, 6} = 15.71$; $P < 0.01$; 35 d: $F_{1, 6} = 9.79$; $P = 0.02$; 42 d: $F_{1, 6} = 5.54$; $P = 0.057$; 49 d: $F_{1, 6} = 7.86$; $P = 0.03$; 56 d: $F_{1, 6} = 9.29$; $P = 0.04$. SPLAT + naled: 14 d: $F_{1, 6} = 13.66$; $P = 0.01$; 21 d: $F_{1, 6} = 16.92$; $P = 0.006$; 28 d: $F_{1, 6} = 9.64$; $P = 0.02$; 35 d: $F_{1, 6} = 13.70$; $P = 0.01$; 42 d: $F_{1, 6} = 17.10$; $P < 0.01$, 49 d: $F_{1, 6} = 5.49$; $P = 0.058$; 56 d: $F_{1, 6} = 9.84$; $P = 0.02$. Min-U-Gel + naled: 14 d: $F_{1, 6} = 0.37$; $P = 0.56$; 21 d: $F_{1, 6} = 8.81$; $P = 0.03$; 28 d: $F_{1, 6} = 5.86$; $P = 0.05$; 35 d: $F_{1, 6} = 17.50$; $P < 0.01$; 42 d: $F_{1, 6} = 38.49$; $P < 0.001$, 49 d: $F_{1, 6} = 10.33$; $P = 0.01$; 56 d: $F_{1, 6} = 10.55$; $P = 0.018$).

ME or C-L + naled or DDVP (Vargas et al. 2008, Mau et al. 2007). In the Hawaii program, a solid formulation with DDVP (Vaportape II, Hercon, Emigsville, PA) strips in place of liquid naled has been an improvement from a worker safety viewpoint. In trials with molded paper fiber dispensers containing ME or C-L with fipronil, results from paired tests (fresh versus weathered dispensers) under typical Hawaiian weather conditions, demonstrate that these Amulet C-L dispensers were effective for at least 77 d (Vargas et al. 2005). Enclosing Amulet ME dispensers inside small plastic traps, extended attraction and kill up to the label replacement interval recommendation of 60 d. Amulet C-L stations inside traps were registered in 2007 through the U.S.

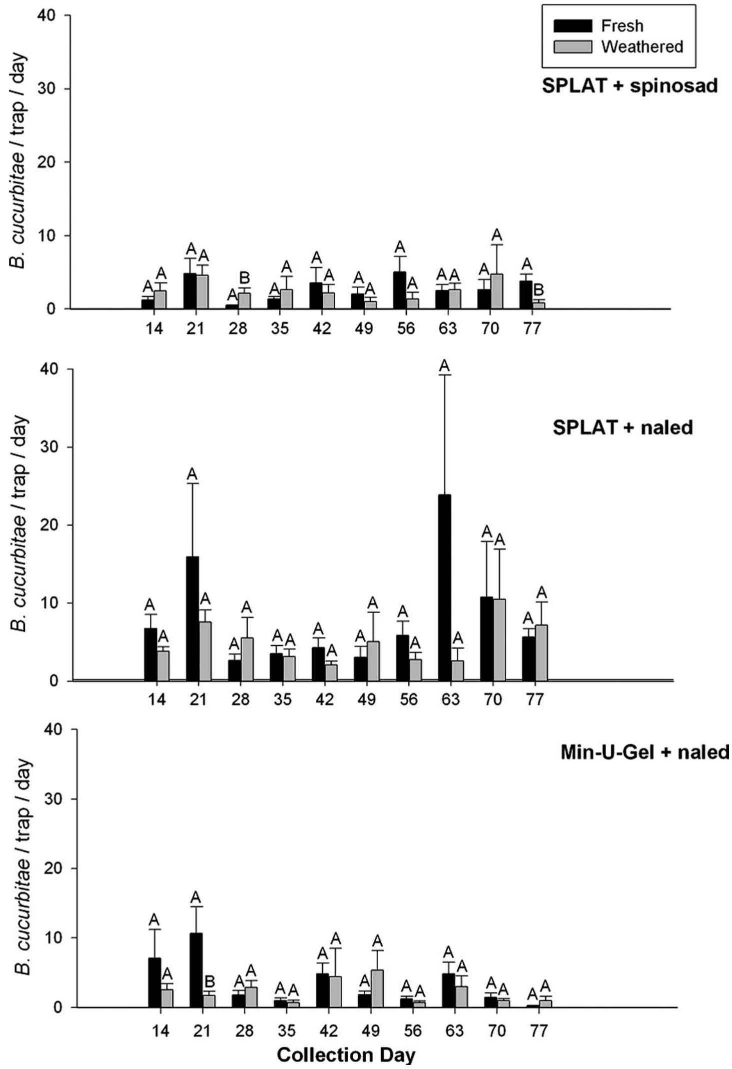

Fig. 4. Captures of *B. cucurbitae* in paired C-L traps with fresh and weathered treatments placed in bitter melon patches at Polihale, HI, from 9 November 2006 to 11 January 2007. Grouped bars with different letters are significantly different (α = 0.05, LSD, PROC GLM, SAS Institute 1999). SPLAT + spinosad: 14 d: $F_{1,6}$ = 1.11; P = 0.33; 21 d: $F_{1,6}$ = 0.00; P = 0.98; 28 d: $F_{1,6}$ = 6.25; P = 0.04; 35 d: $F_{1,6}$ = 0.31; P = 0.6; 42 d: $F_{1,6}$ = 0.28; P = 0.61; 49 d: $F_{1,6}$ = 0.82; P = 0.39; 56 d: $F_{1,6}$ = 2.92; P = 0.14; 63 d: $F_{1,6}$ = 0.00; P = 0.97; 70 d: $F_{1,6}$ = 0.09; P = 0.77; 77 d: $F_{1,6}$ = 8.51; P = 0.03. SPLAT + naled: 14 d: $F_{1,6}$ = 2.71; P = 0.15; 21 d: $F_{1,6}$ = 0.48; P = 0.51; 28 d: $F_{1,6}$ = 0.83; P = 40; 35 d: $F_{1,6}$ = 0.07; P = 0.81; 42 d: $F_{1,6}$ = 2.73; P = 0.14; 49 d: $F_{1,6}$ = 0.10; P = 0.76; 56 d: $F_{1,6}$ = 2.17; P = 0.19; 63 d: $F_{1,6}$ = 3.36; P = 0.12; 70 d: $F_{1,6}$ = 0.00; P = 0.98; 77 d: $F_{1,6}$ = 0.08; P = 0.78. Min-U-Gel + naled: 14 d: $F_{1,6}$ = 1.10; P = 0.34; 21 d: $F_{1,6}$ = 6.68; P = 0.04; 28 d: $F_{1,6}$ = 0.96; P = 0.37; 35 d: $F_{1,6}$ = 0.33; P = 0.58; 42 d: $F_{1,6}$ = 0.25; P = 0.63; 49 d: $F_{1,6}$ = 1.45; P = 0.27; 56 d: $F_{1,6}$ = 1.05; P = 0.34; 63 d: $F_{1,6}$ = 0.61; P = 0.46; 70 d: $F_{1,6}$ = 0.28; P = 0.61; 77 d: $F_{1,6}$ = 1.64; P = 0.25).

Environmental Protection Agency for use against C-L responding fruit flies in the United States. Our combined results indicate that spinosad was as effective as naled in killing *B. dorsalis* and *B. cucurbitae.* For example, SPLAT ME + spinosad performed similarly to the current standard of Min-U-Gel ME + naled up to 6 wk, and it was superior from weeks 7 to 12 in tests conducted in papaya and guava orchards. Clearly, the SPLAT ME + spinosad formulation was more effective at killing *B. dorsalis* than the SPLAT C-L + spinosad formulation at killing *B. cucurbitae.* Field observations suggest that the habit of *B. dorsalis* feeding directly on ME allowed males to ingest more insecticide. Plans are to test SPLAT-spinosad-C-L formulations with the addition of phagostimulants. Spinosad is a reduced risk insecticide not as persistent as naled or malathion. In a previous study, spinosad was successfully tested in ME and C-L traps for suppression of *B. dorsalis* and *B. cucurbitae* in Hawaii (Vargas et al. 2003) and lasted 10–20 wk. The SPLAT ME and C-L + spinosad formulations provide a safer and more convenient sprayable formulation technology for attracting and killing fruit flies that equals the efficacy of Min-U-Gel

+ naled. These SPLAT-spinosad products are unique in that they offer a novel and convenient ready-to-use MAT formulation that contains both a powerful lure and a reduced risk insecticide for fruit fly control by farmers and home gardeners.

In summary, our results suggest that spinosad is a promising substitute for organophosphate insecticides in SPLAT sprayable attract-and-kill formulations with ME and C-L for control of *B. dorsalis* and *B. cucurbitae*, respectively, in Hawaii. These new formulations will be tested further in weathering studies in California. Of particular concern in California has been the use of naled in residential areas on telephone poles and tree trunks during eradication programs. SPLAT ME could be deployed in these environmentally sensitive areas as a much safer alternative to organophosphates. Male annihilation technique approaches should be included with environmentally friendly bait spray treatments such as the spinosad-based GF-120 Fruit Fly Bait. The development of IPM approaches that include the use of both protein bait sprays and MAT dispensers without organophosphates would have important applications to suppression of fruit flies not only in Hawaii but also throughout the south and western Pacific, Australia, tropical Asia, South America, and Africa where *Dacus* and *Bactrocera* are serious economic pests. Recently, two species in the *B. dorsalis* complex were established on two new continents: *Bactrocera carambolae* Drew & Hancock in South America (Suriname) and *Bactrocera invadens* Drew, Tsuruta & White in Africa (Kenya) (Drew et al. 2005, Rousse et al. 2005). Similarly, *Bactrocera zonata* (Saunders) has spread to northern Africa and the Mediterranean area. Because all three species respond to ME, SPLAT ME + spinosad would be useful for areawide suppression in areas where an organophosphate alternative is desirable. Finally, the development of environmentally friendly areawide IPM procedures would have important applications to eradication of accidental introductions of fruit flies into the U.S. mainland and other Pacific nations.

Acknowledgments

We thank Neil Miller (Pacific Basin Agricultural Research Center, USDA–ARS, Hilo, HI) and Russell Ijima, Glenn Asmus, Charles Rodd, Hank Sobeleski, and Charles Brinkmann (Pacific Basin Agricultural Research Center, USDA–ARS, Kapaa, HI) for assistance in collecting field data. IR-4 and USDA–ARS Area-Wide Pest Management funds were essential to planning and completing this research. Finally, we thank Luc Leblanc, Rudolph Putoa, and Victoria Yokoyama for comments on an earlier draft of this manuscript.

References Cited

Allwood, A. J., E. T. Vueti, L. Leblanc, and R. Bull. 2002. Eradication of introduced *Bactrocera* species (Diptera: Tephritidae) in Nauru using male annihilation and protein bait application techniques, pp. 19–25. *In* C. R. Veitch and M. N. Clout [eds.], Turning the tide: the eradication of invasive species. Proceedings of the International Conference on Eradication of Island Invasives. IUCN Publications Services Unit, Cambridge, United Kingdom.

Barry, J. D., S. Polavarapu, and L.A.F. Teixeira. 2004. Evaluation of traps and toxicants in an attract-and-kill system for *Rhagoletis mendax* (Diptera: Tephritidae). J. Econ. Entomol. 97: 2006–2014.

Barry, J. D., N. W. Miller, J. C. Pinero, A. Tuttle, R.F.L. Mau, and R. I. Vargas. 2006. Effectiveness of protein baits on melon fly and oriental fruit fly (Diptera: Tephritidae): attraction and feeding. J. Econ. Entomol. 99: 1161–1167.

Cantrell, B. K., B. Chadwick, and A. Cahill. 2002. Fruit fly fighters: eradication of papaya fruit fly. Commonwealth Scientific and Industrial Research Organization Publishing, Collingwood, VIC, Australia.

Chambers, D. L., R. T. Cunningham, R. W. Lichty, and R. B. Thraikill. 1974. Pest control by attractants: a case study demonstrating economy, specificity, and environmental acceptability. Bioscience 24: 150–152.

Cunningham, R. T., and D. Y. Suda. 1985. Male annihilation of the oriental fruit fly (Diptera: Tephritidae): a new thickener and extender for methyl eugenol formulations. J. Econ. Entomol. 78: 503–504.

Cunningham, R. T., D. L. Chambers, and A. G. Forbes. 1975a. Oriental fruit fly: thickened formulations of methyl eugenol in spot applications for male annihilation. J. Econ. Entomol. 68: 861–863.

Cunningham, R. T., D. L. Chambers, L. F. Steiner, and K. Ohinata. 1975b. Thixcin-thickened sprays of cue-lure + naled: investigation of rates of application for use in male annihilation of melon fly. J. Econ. Entomol. 68: 857–860.

Drew, R.A.I., K. Tsuruta, and I. M. White. 2005. A new species of pest fruit fly (Diptera: Tephritidae: Dacinae) from Sri Lanka and Africa. Afr. Entomol. 13: 149–154.

DowElanco. 1994. Spinosad technical guide. DowElanco, Indianapolis, IN.

Hardy, D. E. 1979. Review of economic fruit flies of the South Pacific Region. Pac. Insects 20: 429–432.

Koyama, J., T. Teruya, and K. Tanaka. 1984. Eradication of the oriental fruit fly (Diptera: Tephritidae) from the Okinawa Islands by a male annihilation method. J. Econ. Entomol. 77: 468–472.

Lloyd, A., P. Leach, and R. Kopittke. 1998. Effects of exposure on chemical content and efficacy of male annihilation blocks used in the eradication of *Bactrocera papayae* in North Queensland. Gen. Appl. Entomol. 28: 1–8.

Mau, R.F.L., E. B. Jang, and R. I. Vargas. 2007. The Hawaii fruit fly area-wide fruit fly pest management programme: influence of partnership and a good education programme, pp. 671–683. *In* M.J.B. Vreysen, A. S. Robinson, and J. Hendrichs [eds.], Areawide control of insect pests: from research to field implementation. Springer, Dordrect, The Netherlands.

Metcalf, R. L., and E. R. Metcalf. 1992. Fruit flies of the family Tephritidae. *In* R. L. Metcalf and E. R. Metcalf [eds.], Plant kairomones in insect ecology and control. Routledge, Chapman & Hall, New York.

Prokopy, R. J., N. W. Miller, J. C. Piñero, J. D. Barry, L. C. Tran, L. K. Oride, and R. I. Vargas. 2003. Effectiveness of GF-120 fruit fly bait spray applied to border area plants for control of melon flies (Diptera: Tephritidae). J. Econ. Entomol. 96: 1485–1493.

Rousse, P., E. J. Harris, and S. Quilici. 2005. *Fopius arisanus,* an egg-pupal parasitoid of Tephritidae. Overview. Biocontrol News and Information. 26: 59N–69N. CAB International, Wallingford, United Kingdom. (Pest.cabweb.org).

SAS Institute. 1999. SAS/STAT user's guide, version 6. SAS Institute, Cary, NC.

Stark, J. D., and R. I. Vargas. 2003. Demographic changes in *Daphnia pulex* (Leydig) after exposure to the insecticides, spinosad and diazinon. Ecotoxicol. Environ. Saf. 56: 334–338.

Stark, J. D., R. I. Vargas, and N. W. Miller. 2004. Toxicity of spinosad in protein bait to three economically important tephritid fruit fly species (Diptera: Tephritidae) and their parasitoids (Hymenoptera: Braconidae). J. Econ. Entomol. 97: 911–915.

Steiner, L. F., W. C. Mitchell, E. J. Harris, T. T. Kozuma, and M. S. Fujimoto. 1965. Oriental fruit fly eradication by male annihilation. J. Econ. Entomol. 58: 961–964.

Steiner, L. F., W. G. Hart, E. J. Harris, R. T. Cunningham, K. Ohinata, and D. C. Kamakahi. 1970. Eradication of the oriental fruit fly from the Mariana Islands by the methods of male annihilation and sterile insect release. J. Econ. Entomol. 63: l3l–l35.

Stelinski, L. L., J. R. Miller, R. Ledebuhr, P. Siegert, and L. J. Gut. 2007. Season-long mating disruption of *Grapholita molesta* (Lepidoptera: Tortricidae) by one machine application of pheromone in wax drops (SPLAT-OFM). J. Pestic. Sci. 80: 109–117.

Vargas, R. I., J. D. Stark, M. H. Kido, H. M. Ketter, and L. C. Whitehand. 2000. Methyl eugenol and cue-lure traps for suppression of male oriental fruit flies and melon flies (Diptera: Tephritidae) in Hawaii: effects of lure mixtures and weathering. J. Econ. Entomol. 93: 81–87.

Vargas, R. I., N. W. Miller, and J. D. Stark. 2003. Field trials of spinosad as a replacement for naled ddvp, and malathion in methyl eugenol and cue-lure bucket traps to attract and kill male oriental fruit flies and melon flies (Diptera: Tephritidae) in Hawaii. J. Econ. Entomol. 96: 1780–1785.

Vargas, R. I., J. D. Stark, B. Mackey, and R. Bull. 2005. Weathering trials of Amulet Cue-lure and methyl eugenol "attract and kill" stations with male melon flies and oriental fruit flies (Diptera: Tephritidae) in Hawaii. J. Econ. Entomol. 98: 1551–1559.

Vargas, R. I., R.F.L. Mau, E. B. Jang, R. M. Faust, and L. Wong. 2008. The Hawaii Fruit Fly Area-Wide Pest Management Program, pp. 300–325. *In* O. Koul, G. W. Cuperus, and N. C. Elliott [eds.], Areawide IPM: theory to implementation. CABI Books, London, United Kingdom.

Weems, H. V. 1964. Melon fly (*Dacus cucurbitae* Coquillett) (Diptera: Tephritidae). Entomology Circular, Division of Plant Industry, Florida Department of Agriculture and Consumer Services 21: 1–2.

White, I. M., and M. M. Elson-Harris. 1992. Fruit flies of economic significance: their identification and bionomics. CAB International, Wallingford, United Kingdom.

Received 23 September 2007; accepted 9 February 2008.